

2016

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Recommended Citation

Omar, Gihan; Abdelsalam, Zeinab; and Hamed, Walaa (2016) "Quantitative analysis of metallic artifacts caused by dental metallic restorations: Comparison between four CBCT scanners," *Future Dental Journal*: Vol. 2 : Iss. 1 , Article 3.

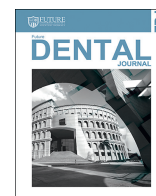
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Quantitative analysis of metallic artifacts caused by dental metallic restorations: Comparison between four CBCT scanners

Cover Page Footnote

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Quantitative analysis of metallic artifacts caused by dental metallic restorations: Comparison between four CBCT scanners



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ARTICLE INFO

Article history:

Received 3 February 2016

Accepted 12 April 2016

Available online 15 May 2016

ABSTRACT

Purpose: The objective of this study was to quantitatively evaluate the artifacts produced by different metallic restorations using four cone-beam computed tomography (CBCT) scanners.

Methods: Eight extracted teeth (four mandibular premolars and four mandibular molars) were randomly divided into four groups. Each group compromised one premolar and one molar. One group was prepared and restored with occluso-mesial amalgam restorations (MO), the second group with mesio-occluso-distal amalgam restorations (MOD), the third group with porcelain fused to metal full coverage restoration, and the fourth group with occluso-mesial indirect metallic restorations (inlays). The restored teeth were then placed in the sockets of dried mandible. Images were obtained using four different cone beam computed tomography (CBCT) scanners, with exposure parameters 85 kVp and 8 mA. Volumes of artifacts were then measured by segmentation using volumetric and 8i thresholding methods.

Results: Quantitative evaluation of metallic artifacts using the volumetric method showed the greatest mean value obtained from J Morita for all types of restorations studied while when using the thresholding method Gallileos yielded the greatest mean value for crown, MO, and inlay restoration while scanora produced the greatest mean value for MOD restorations.

Conclusion: In cases of scanning patients with multiple fixed restorations Scanora is recommended. In cases of patients with MO or inlay restorations Planmeca AINO™ is recommended. Gallileos and J Morita are acceptable for scanning patients with metallic restorations and recommended in cases of MOD amalgam restorations.

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1. Introduction

Use of CBCT in dental procedures has increased in recent years due to its low cost, fast image production rate and its low radiation dose in comparison with CT. CBCT appears to have a high potential in the diagnosis and treatment planning, especially in implant treatments, by providing three-dimensional images [12,30].

Although, it is a widely used method for 3D radiographic assessment in dentistry, it should not be elapsed that there are intrinsic limitations and artifacts regarding this technique. Artifacts

are induced by discrepancies between the mathematical modeling and the actual physical imaging process [17,29].

An image artifact may be defined as a visualized structure in the reconstructed data that is not present in the object under investigation [4]. CBCT image artifacts may be attributed to small field of view (FOV) or divergence of the cone beam resulting in aliasing artifacts, also small flat panel detector (FPD) may result in ring artifacts. In addition, unexpected movements cause double contours called motion artifacts [13,29,32] which can be solved by sufficient fixation of the patient's head during the scan and increase in the mechanical stability of the system [4,8,13,29,32,36].

Moreover, imaging of highly absorbing materials may cause missing value artifacts, beam hardening artifacts or exponential edge gradient effect which appear as cupping artifact, streaks and dark bands between dense objects or streaks at sharp edges with

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Peer review under responsibility of Faculty of Oral & Dental Medicine, Future University.

<http://dx.doi.org/10.1016/j.fdj.2016.04.001>

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high contrast to neighboring structures [27,28].

Beam hardening artifact is one of the most prominent sources of artifacts [4,5] caused by absorption of lower wavelength rays when passing through the object. The lower energetic (lower wavelength) rays of the polychromatic spectrum emitted by the X-ray source may suffer substantial absorption when passing through the object under study. The denser the object and the higher its atomic number, the larger the range of absorbed wavelengths [29].

Examination of metal bodies as dental fillings or dental implants usually uses high-density metal materials, such as gold alloy, amalgam and titanium which cause severe beam hardening and scattering effect artifacts [15]. Metal artifacts influence the image quality by reducing the contrast, obscuring structures and impairing the detection of areas of interest, thereby making the diagnosis difficult and time-consuming [25,34].

Methods for reducing metallic artifacts in CBCT images have been documented, but these techniques cannot completely remove streak artifacts. Previous studies have evaluated metallic artifacts in CBCT images [29]. However, the majority of these studies have been qualitative ones. A few studies have quantitatively compared CBCT X-ray machines [12].

Given the paucity of studies, particularly studies comparing CBCT X-ray machines with each other, studies appear to be necessary in this respect. The aim of the present study was to compare the artifacts produced by different metallic restorations commonly used in dentistry scanned by four different CBCT scanners.

2. Materials and methods

Two edentulous dry mandibles were borrowed from the Anatomy Department, School of Medicine Ain-shams University. Eight extracted teeth (four mandibular premolars and four mandibular molars) were randomly divided into four groups. Each group compromised one premolar and one molar. The first group was prepared and restored with occluso-mesial amalgam restorations (MO), the second group with mesio-occluso-distal amalgam restorations (MOD), the third group with porcelain fused to metal full coverage restoration, and the fourth group with occluso-mesial indirect metallic restorations (inlays).

The restored teeth were placed in the prepared sockets of dried mandible. Each mandible received 2 premolars and 2 molars from the same group of the previously mentioned dental restoration. The extracted teeth were fixed in their corresponding sockets in each dry mandible with pink wax. All mandibles were completely immersed with water during scanning by fixing them in a water-filled plastic holder container (to compensate for the absence of soft tissue).

2.1. CBCT imaging

Images of the two mandibles were obtained using four different CBCT scanners, with accelerating voltage set at 85 kVp and the X-ray beam current at 8 mA to avoid influence of varying exposure parameters on the image quality [21]:

1. Planmeca ProMax 3D Proface (Planmeca Oy, Helsinki, Finland) with FPD, 0.2 mm voxel size.
2. Planmeca ProMax 3D Proface (Planmeca Oy, Helsinki, Finland) with FPD, 0.2 mm voxel size. With the use of Planmeca AINO™ (Adaptive Image Noise Optimiser)
3. Galileos comfort, Sirona dental, Germany with Image intensifier (IIT), 0.3 mm.
4. Veraviewepocs 3D model X550 (J Morita MfgCorp., Kyoto, Japan) with a FPD, 0.125 mm voxel size.

5. Scanora3D (Scanora 3D, Soredex, Helsinki, Finland) with CMOS FPD with isotropic voxel size 0.35 mm.

2.2. Image analysis

All CBCT raw DICOM data set images were imported to their integrated software and selection of the cuts, secondary reconstruction of the data was performed using a third party software.¹

The images were evaluated by two independent observers, who were oral and maxillofacial radiologists each with more than 4 years of experience in the analysis of CBCT scans. Then quantitative assessment of metallic artifacts volumes was done by two different segmentation methods using Simplant software as follows:

2.3. 1-Segmentation by smart pen tool

The 3 orientation lines (axial, coronal and sagittal lines) were adjusted and viewed. The streak artifacts were evaluated by using the smart pen tool available by the Simplant software. The tooth with the coronal restoration and the resultant artifacts were segmented precisely and the volume was calculated in mm³. By the same way, the tooth and the restoration only were segmented and the volume was calculated. So by subtractions, the volume of artifacts was obtained. The volume of (the tooth + the artifact) – the volume of the tooth = the volume of artifacts (Fig. 1).

2.4. 2- Segmentation by thresholding

On axial image, thresholding tool was used to identify all pixels within a certain Hounsfield range with a certain color (called mask). In another word, threshold values are range of densities displayed to obtain a metallic artifact volume. The threshold range was manually set by changing the minimum and maximum values, only the pixels falling within the designated range formed a color coded mask.

So, proper adjustment of thresholding (gray scale) was adjusted individually for each CBCT data set to facilitate delineation of the metallic artifact (Fig. 2).

2.5. Statistical evaluation

Analysis of data was performed using SPSS 17 (Statistical Package for Scientific Studies) for Windows. Description of quantitative variables was in the form of mean, standard deviation (SD). Data were explored for normality using Kolmogorov-Smirnov test of normality. The results of Kolmogorov-Smirnov test indicated that most of data were normally distributed (parametric data) so parametric tests were used for the comparisons. Different techniques were compared using analysis of variance (ANOVA) test, followed by Tukey's post hoc test when a significant difference was detected.

Results were expressed in the form p-values that were differentiated into:

- * Non-significant when p-value >0.05
- * Significant when p-value ≤0.05

¹ Simplant Pro 15, DENTSPLY, Belgium.

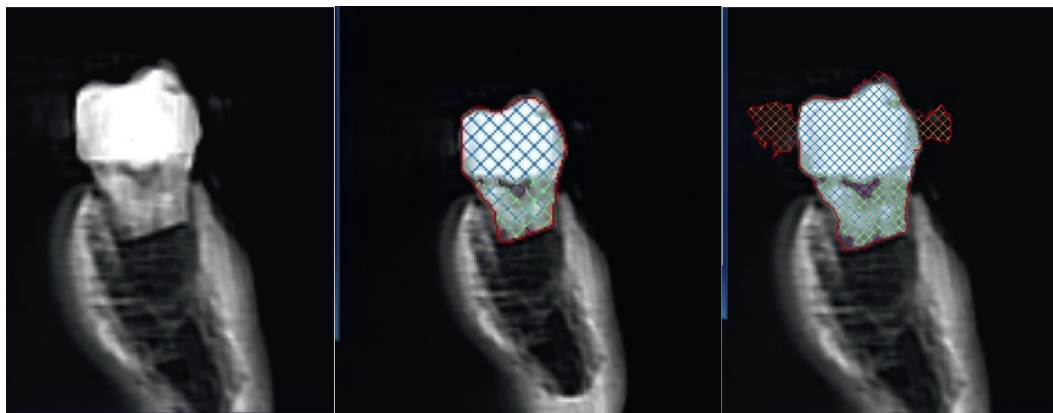


Fig. 1. Simplant software, cross sectional cuts: a molar with PFM crown with artifact (Left), outline of real crown and abutment (middle), and outline of crown with abutment as well as artifact in vicinity of the real image by smart pen tool (Right).

3. Results

3.1. 1- Quantitative evaluation of metallic artifacts using segmentation by smart pen tool

Regarding artifacts recorded in crown, the greatest mean value was obtained using J Morita, whereas the least value was recorded by Scanora. ANOVA test revealed a statistically significant difference between the different CBCT machines ($p < 0.0001$). Tukey's post hoc test revealed a significant difference between each two techniques (Table 1, Fig.3).

Regarding artifacts recorded in MO, the greatest mean value was obtained using J Morita, whereas the least value was recorded by Planmeca with artifact removal. ANOVA test revealed a statistically significant difference between the different techniques ($p < 0.0001$). Tukey's post hoc test revealed a significant difference between each two techniques, except between Planmeca AINO™ and Galileo's (Table 1, Fig. 3).

Regarding artifacts recorded in MOD, the greatest mean value

was obtained using J Morita, whereas the least value was recorded by Galileo's. ANOVA test revealed a statistically significant difference between the different CBCT machines ($p < 0.0001$). Tukey's post hoc test revealed a significant difference between each two techniques (Table 1, Fig. 3).

Regarding artifacts recorded in inlay, the greatest mean value was obtained using J Morita, whereas the least value was recorded by Planmeca AINO™. ANOVA test revealed a statistically significant difference between the different CBCT machines ($p < 0.0001$). Tukey's post hoc test revealed a significant difference between each two techniques, except between Planmeca and Gallileos (Table 1, Fig. 3).

3.2. II- quantitative evaluation of metallic artifacts using segmentation by thresholding

Regarding artifacts recorded in crown, the greatest mean value was obtained using Galileo's, whereas the least value was recorded by Scanora. ANOVA test revealed a statistically significant

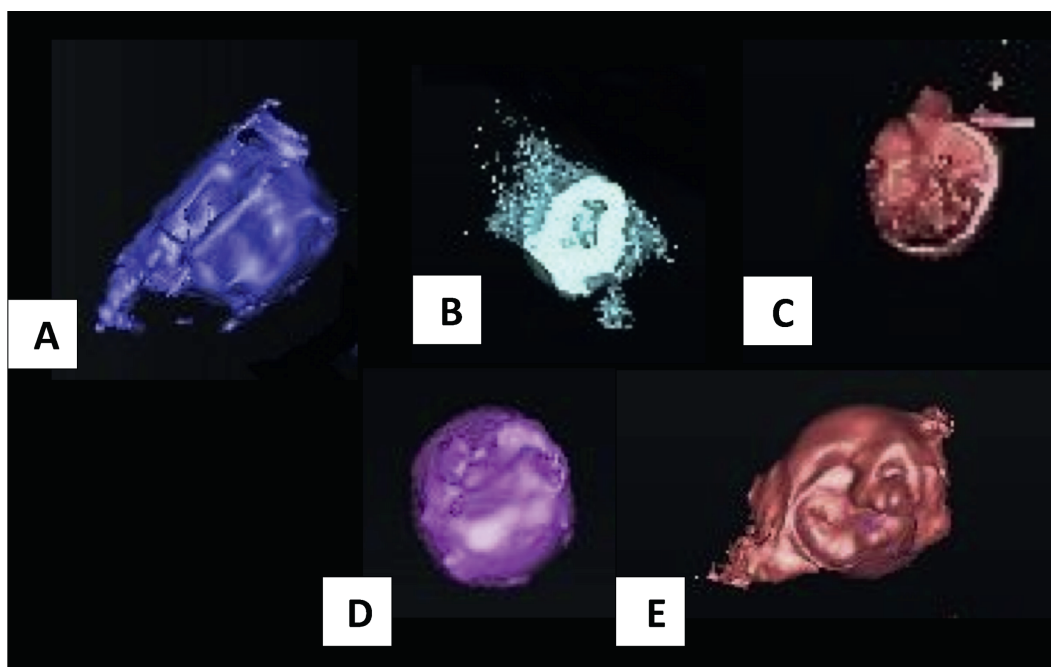


Fig. 2. 3D volume rendering images showing PFM crown with artifact by thresholding method. (A) Scanora, (B) Gallileos, (C) J morita (D) Planmeca with artifact removal, and (E) Planmeca.

Table 1

Mean \pm SD of values of volume of metallic artifacts obtained by segmentation by smart pen tool using different CBCT machines and significance of the difference using ANOVA test.

| Segmentation by smart pen tool | Crown | MO | MOD | Inlay |
|--------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| Planmeca | 1660.7 ^a \pm 154.2 | 1094.45 ^a \pm 96.2 | 1386.24 ^a \pm 176.2 | 1134.33 ^a \pm 125.2 |
| Planmeca AINO™ | 1270.21 ^b \pm 113.6 | 680.05 ^b \pm 76.3 | 814.29 ^b \pm 86.9 | 575.03 ^b \pm 49.5 |
| Galileo's | 1483.31 ^c \pm 124.5 | 710.93 ^b \pm 85.3 | 653.47 ^c \pm 71.8 | 1072.32 ^a \pm 97.6 |
| Scanora | 661.44 ^d \pm 54.2 | 910.81 ^c \pm 89.1 | 1215.74 ^d \pm 188.2 | 971.71 ^c \pm 88.4 |
| J Morita | 3243.24 ^e \pm 297.4 | 1937.99 ^d \pm 188.5 | 2248.05 ^e \pm 250.8 | 2250.3 ^e \pm 212.76 |
| F value | 319.65 | 159.72 | 130.98 | 243.4 |
| P value | <0.0001* | <0.0001* | <0.0001* | <0.0001* |

*Statistically significant.

Tukey's post hoc test: means with different superscript letters are significantly different.

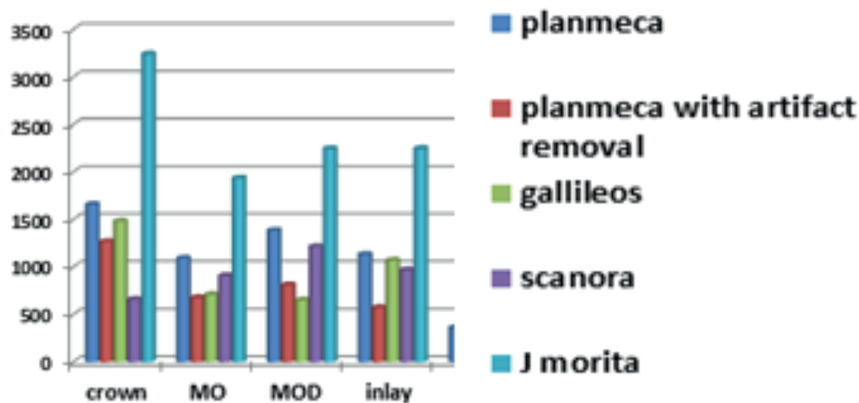


Fig. 3. Column chart showing mean values of volume obtained by different CBCT machines using segmentation by smart pen tool.

difference between the different techniques ($p < 0.0001$). Tukey's post hoc test revealed a significant difference between each two techniques, except Galileo's and J Morita (Table 2, Fig. 4).

Regarding artifacts recorded in MO, the greatest mean value was obtained using Galileo's, whereas the least value was recorded by Planmeca. ANOVA test revealed a statistically significant difference between the different techniques ($p < 0.0001$). Tukey's post hoc test revealed a significant difference between each two techniques, except between Planmeca AINO™ and Scanora (Table 2, Fig. 4).

Regarding artifacts recorded in MOD, the greatest mean value was obtained using Scanora, whereas the least value was recorded by J Morita. ANOVA test revealed a statistically significant difference between the different techniques ($p < 0.0001$). Tukey's post hoc test revealed a significant difference between each two techniques, except between Planmeca and J Morita (Table 2, Fig. 4).

Regarding artifacts recorded in inlay, the greatest mean value was obtained using Galileo's, whereas the least value was recorded by Planmeca. ANOVA test revealed a statistically significant difference between the different techniques ($p < 0.0001$). Tukey's post

hoc test revealed a significant difference between each two techniques, except between Planmeca AINO™ and Scanora (Table 2, Fig. 4).

4. Discussion

Evaluation and comparison of different CBCT machines in relation to the extent of metallic artifacts are very important because in some cases the artifacts are so extensive that image quality decreases or even the image is distorted [35,38]. From this issue, this study was designed to quantitatively evaluate the artifacts produced by different metallic restorations using four cone-beam computed tomography scanners.

Human subjects were excluded from the study and the diagnostic capabilities of the imaging modalities were investigated on dry mandibles and extracted teeth to simulate the real clinical situation. Another reason was to avoid interference of factors that could impede the quality of examination as motion of patient, as well as the possibility of presence of other metallic structures that

Table 2

Mean \pm SD of values of volume artifact obtained by thresholding method using different techniques and significance of the difference using ANOVA test.

| Segmentation by thresholding | Crown | MO | MOD | Inlay |
|------------------------------|----------------------------------|--------------------------------|--------------------------------|--------------------------------|
| Planmeca | 563 ^a .04 \pm 43.3 | 222.65 ^a \pm 34.2 | 348.28 ^a \pm 40.2 | 235.63 ^a \pm 21.6 |
| Planmeca AINO™ | 737.51 ^b \pm 81.3 | 305.48 ^b \pm 43.1 | 430.75 ^b \pm 51.8 | 304.68 ^b \pm 30.2 |
| Galileo's | 1090.47 ^c \pm 220.6 | 534.29 ^c \pm 64.3 | 503.06 ^c \pm 49.6 | 836.03 ^c \pm 94.3 |
| Scanora | 161.78 ^d \pm 23.7 | 290.6 ^b \pm 27.54 | 624.22 ^d \pm 58.4 | 325.05 ^b \pm 33.4 |
| J Morita | 984.81 ^c \pm 201.2 | 415 ^d \pm 38.3 | 343.23 ^a \pm 29.7 | 544.45 ^d \pm 60.2 |
| F value | 202.14 | 80.2 | 60.14 | 169.9 |
| P value | <0.0001* | <0.0001* | <0.0001* | <0.0001* |

*Statistically significant.

Tukey's post hoc test: means with different superscript letters are significantly different.

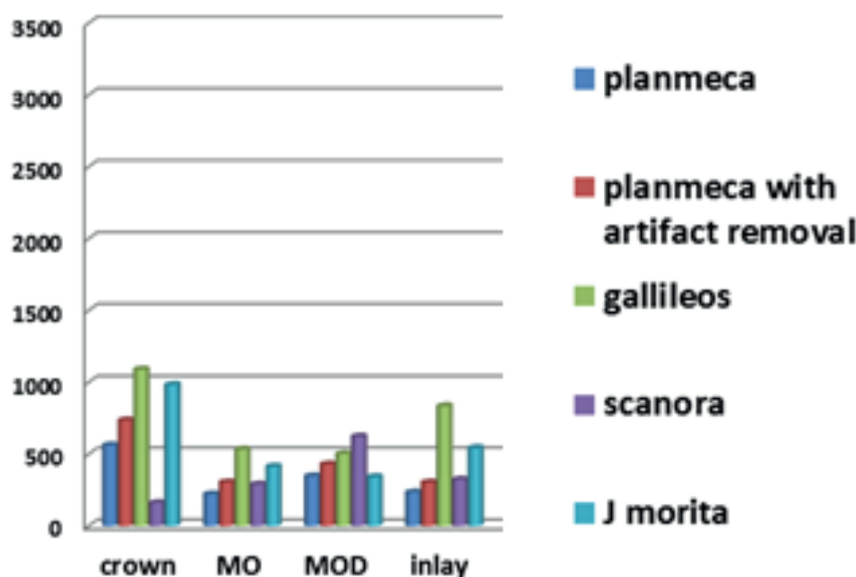


Fig. 4. Column chart showing mean values of volume obtained by different CBCT machines using segmentation by thresholding.

could affect the quality of the final image other than the tested factors [1].

Nickel–chromium alloy is used in dental treatment for indirect restorations presented as inlays and the metal part of the porcelain fused to metal crown and amalgam restorations which are used due to their high density and are still found in patients as restoration. MOD and MO designs were selected because they are more liable to affect diagnosis of proximal caries and interproximal bone loss. In this work, different metallic materials were investigated for their potentiality to cause artifacts in CBCT imaging. The examined metals were of typical clinical use nowadays, making the results more clinically relevant.

All mandibles were completely covered with water during scanning by fixing them in a water-filled plastic holder to compensate the absence of the soft tissues. All mandibles with the previously mentioned groups of restorations were scanned with four different CBCT machines, with the same mA or kVp to avoid interference and influence of varying exposure parameters on the image quality and consequently on the recorded data.

The raw DICOM data set obtained from the four CBCT scanners were imported to special third party software, Simplant for secondary reconstruction so as to neutralize the role of the software and to render any variations in the recorded data to the differences between both modalities not between the applied soft wares to avoid biased results.

In this study, streak artifacts from metallic coronal restorations were assessed by using the segmentation tool of the third party software. In this method, the volume of artifacts that were in a close proximity to the restoration and having opaque voxel values were included and evaluated. This method allows assessment of the artifacts from all possible directions; in other words in the 3 planes.

The lack of clear boundaries to metallic artifacts in CBCT images means that no standard method of quantifying the artifact area exists. We therefore established threshold values for the black and white components according to the method reported by Ref. [33]. The results of the present study showed that a statistically significant difference was found between the different CBCT scanners regarding the values recorded in crown, MO, MOD, inlay in both volumetric and thresholding methods which may be due to different type of detectors, FOV or voxel size [26].

In addition, CBCT machine with FPD was used owing to the fact that these detectors are superior to IIT/CCD in terms of their increased dynamic range, contrast and spatial resolution, decreased pixel noise and image artifacts as mentioned by Ref. [19] and then by Ref. [18]. In addition, FPDs have an improved performance and image quality, a view which is supported by Ref. [31].

Furthermore, as mentioned by Seeram 2001 CBCT machines with FPDs have higher quantum detection efficiency than those with an IIT, i.e. they are more efficient at recording signals from photons reaching the detector. This view is also supported by Refs. [3,6,11]. Moreover; FPDs are not associated with geometric distortion unlike IITs, as confirmed by Refs. [30,31].

In this study, the selected CBCT machine was a FPD-based system with an adjustable FOV as it is considered as one of the CBCT machines with a significant superiority due to the influence of different FOV selection during the scan as recommended by Ref. [16].

CBCT scanning was done with a small FOV of 7.5 cm × 14.5 cm × 14.5 cm. This FOV was comfortably large enough to scan the teeth bearing area. Using a limited FOV was recommended by Ref. [19] who reported that smaller FOV selection provides better resolution and contrast in comparison with large FOV, and this improves the clarity and visibility of CBCT images.

In contrast, increasing the tube current only reduced the artifact area under some conditions. This finding is consistent with previous studies that also found a significant reduction in metallic artifacts with increased tube voltage, but not with increased tube current [37]. Other studies have also demonstrated no reduction in metallic artifacts with increased tube current when scanning body regions or phantoms with metallic prostheses [14].

It has been reported by Ref. [10] that there may be discrepancies in grey levels owing to inherent deficiencies in the FPD used in some dental CBCT machines. In addition to this problem, there are the effects of scatter and beam hardening. The CBCT devices employ an area detector such as a FPD or IIT which capture more scattered photons than a linear array detector.

Regarding volumetric method, J Morita produced highest artifact volume with all restoration types with a statistically significant difference from other CBCT machines which may be due to its small voxel size.

It was found by many authors that by reducing the voxel size will increase the spatial resolution [9,22]. Many CBCT machines that offer small voxel sizes are being advertised as providing the best image quality for diagnostic purposes based on an assumption that a smaller voxel size will increase the image quality. An important aspect of image quality in CBCT other than spatial resolution is contrast resolution. Contrast resolution is referred to as the ability of an imaging modality to distinguish between various contrast levels in an acquired image [23].

A smaller voxel will not detect as many X-ray photons as would a larger voxel size. A decrease in the number of photons acquired by a voxel would result in a decrease in signal leading to an increase in noise. Tanimoto et al. evaluated the effects of changing the voxel size on the resolution and noise of CBCT reconstruction images (26). The voxel sizes used for reconstruction were 0.05, 0.12, and 0.12 using prototype software for the Accuitomo F8 (J. Morita, Kyoto, Japan). When the voxels were smaller, the noise increased. Their findings show that decreasing the voxel size increases the noise which conforms to the results in the current paper.

Another study done by Lee et al. showed that although the image quality is improved by increasing the spatial resolution. Yet, higher spatial resolution leads to an increased noise level on the reconstructed image. In their study, the effects of reconstruction parameters on the image noise and the spatial resolution were evaluated and the relationship between the image noise and the spatial resolution was examined in a CBCT system. The reconstruction filters, the number of projections, and the voxel size were used as reconstruction parameters.

A study done by Ref. [24] to assess artifacts induced by metallic restorations in three-dimensional (3D) dental surface models derived by CBCT concluded that metallic restorations induce considerable artifacts in 3D dental surface models. Artifact reduction should be taken into consideration for a proper diagnosis and treatment planning when using 3D surface model derived by CBCT in dentofacial deformity patients.

Highest metallic artifacts were produced by crown restoration assessed by all CBCT machines except Scanora which showed highest metallic artifacts were produced by MOD restorations. Increasing tube voltage, but not tube current, could reduce the artifact area under most conditions. The selection of prosthesis materials that produce smaller artifacts and the use of appropriate imaging parameters could therefore reduce artifacts detected on CT images.

In addition, voxel size can influence the characteristics of the final image in several ways. It may influence noise in the orthogonal sections of an image: the smaller the voxel size, the greater the noise, but of course, the higher the spatial resolution [2]. Depending on the voxel size, radiopaque structures can become invisible. This can be caused by the partial volume averaging effect, which is a common computed tomography artifact and occurs when a voxel lies on the borders of two objects of different densities. This voxel will then reflect the average density of both objects rather than the true value of either object [3]. This “invisibility” of some structures could also be caused by the limitations in contrast resolution related to CBCT units, which determines the ability to distinguish two objects of similar densities and in close proximity [7,20].

Upon applying the method of thresholding, it can be concluded that Scanora yield least artifact volume in crown restorations which may be due to large voxel size when compared with other CBCT machines. As for the MO and inlay restorations, the Planmeca AINO™ software option Planmeca AINO™ serves as noise filter that reduces noise in CBCT images while preserving valuable details.

Planmeca AINO™ is enabled from Planmeca Romexis® 3D image capturing dialog according to the patient case and diagnostic need. The software Analyses exposure data during reconstruction and

adaptively differentiates noise and fine details. The original image is stored in the reconstruction PC (100 exposure buffer) and can be recalled in Planmeca Romexis.

Finally, Gallileos produced the least artifacts on scanning MOD restorations which were surprising as the detector used is image intensifier which is known to introduce noise into the images. Results may be influenced by other factors such as number of projections and voxel size.

5. Conclusion

In cases of scanning patients with multiple fixed restorations Scanora is recommended.

In cases of patients with MO or inlay restorations Planmeca AINO™ is recommended.

Gallileos and J Morita are acceptable for scanning patients with metallic restorations and recommended in cases of MOD amalgam restorations.

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